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Second Wind

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SECOND WIND

by

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Abstract

Second Wind is a kinetic, responsive art installation which examines invisible processes taking place in and around a Ponderosa pine tree. Wind speed data, measured at 20', 25', 30', 35', and 40' in the canopy of a Ponderosa on the University of Montana campus, is translated into the gallery in real time using two Raspberry Pi single-board computers. This data determines the velocity of five fans in the gallery. Each fan interacts with a suspended vellum paper structure which moves more or less depending on wind speed. The vellum is painted with an ink made of fermented pine needles from the tree, and imagery depicts changes in canopy density based on height.

This piece is one of a series of works exploring the often-hidden mechanics of plant physiology, aiming to transform these microscopic or invisible processes into analogues viewers can experience in a tangible way. Perhaps engaging with these interpretations of plants as entities in dynamic relationships with their surroundings can contribute to our ability to think more critically about our capacity to both fit within and radically change our ecosystems.

However, this understanding comes with a caveat. While translating wind data into the gallery makes that otherwise invisible and ephemeral force concrete, the viewer is only able to see the fabricated structures which signify the tree, not the tree itself. As the data comes into focus, the tree becomes more abstract. Second Wind aims to raise questions about the limits of perception and knowledge, limits which are especially important to investigate as our capacity to shape our ecosystems continues to grow. I hope to join an expanding critical dialogue questioning the role of object-making, scientific inquiry, and data materialization in how we conceptualize nature and our place within it.

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Contents

1. Introduction

A Brief Overview of Earlier Work About Plant Systems

When I moved to Montana for graduate school, I began spending as much time as I could exploring the landscape. While scrambling across ridgelines and biking through our national forests, I was struck by the stark differences in plant life from my east coast home. Many of these differences could be explained by a plant's use of water, so I began to use art to interpret the processes, invisible to us, which enable plants to survive in challenging environments.

The first pieces in this body of work, from spring 2017, addressed water transport and drought in the Ponderosa pine—looking specifically at tension in chains of polar-bonded water molecules moving upward in the plant stem against the force of gravity. I attempted to situate objects in space so viewers could walk around, behind, and inside analogues of the plant stem, experiencing this tension viscerally.

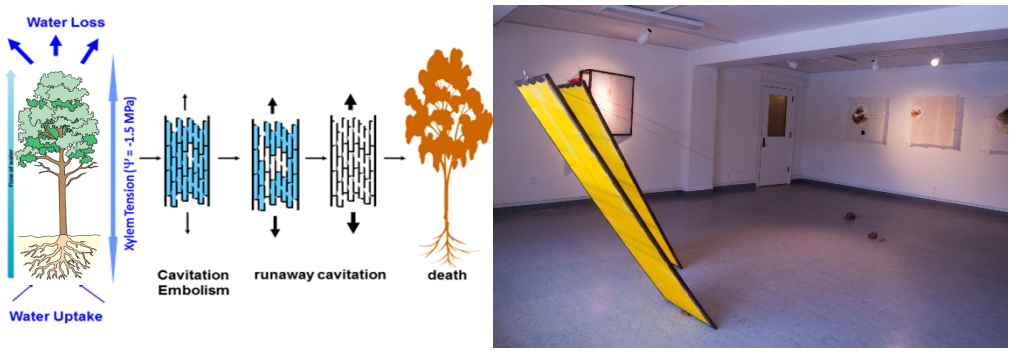


Diagram illustrating cavitation in plant cellular systems (left), and installation view of Attempting Physical Contact With Geologic Time *(right)*

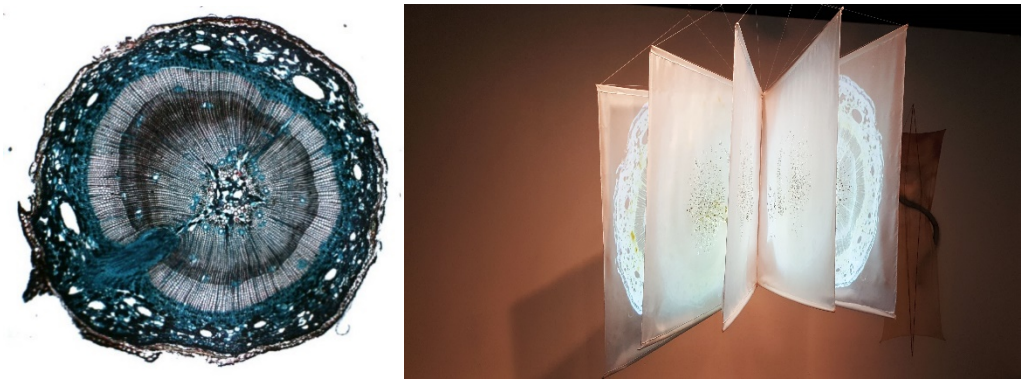


Image of cross-section of 2-year old Ponderosa seedling from collaborator Gerard Sapés and Sala Lab (left), and Ponderosa*, 2017 installation with dual-sided projection over hand-burned holes in panels of silk (right)*

In the fall, I developed a show for the University Center Gallery looking at plant adaptations more broadly, which led to an investigation of the precise symbiotic fit between the Mucuna vine and its bat pollinator. I wanted to configure the installation space so a viewer might feel compelled by an implicit promise of information or illumination.

Tell Me There's a Mathematical Equation For Being Alive *(left, image: Brock Mickelsen), and Mucuna (right)*

By spring of 2018, I began working with a MIDIsprout to collect data on plants' electromagnetic impulses and translate it into sound. I found this output surprising, because sonifying objective data involved subjective decisions about pitch, tempo, and volume.

Sonifying biodata with MIDIsprout device and synthesizer (left and center), and MIDIsprout data visualized with red pencil in a digital drawing on a lithograph (right)

In September, I sonified a stand of ten mature Ponderosa pines at Blackfoot Pathways Sculpture in the Wild in Lincoln, Montana, using a series of sound-generating circuits to translate subtle changes in wind, temperature, and light into changes in pitch, tempo, and volume. Each circuit was placed at the base of a corresponding tree, and sound descended from a speaker in the canopy. A viewer moving through the piece could experience these changes in real time—and I began thinking about how to translate this kind of experience into the gallery.

Circuitry and housings of Tree Talk*, Blackfoot Pathways Sculpture in the Wild, Lincoln MT (images: Brock Mickelsen)*

How **Second Wind** ***Works***

Most of us can recall seeing a tree bend under pressure from wind. Many of the other physiological impacts of wind on a tree, however, are more difficult to visualize and understand. A tree needs to move water up from the ground to hydrate its cells—and to do this, it uses transpiration. Drier air draws moisture up the trunk, through branches and needles, and finally out of the tree through stomata, valve-like openings in the surface of the needles. If this process happens too quickly, however, the tension on the bonds between water molecules increases, almost like a rubber band pulled in two directions. With too much tension the chain can snap, causing an embolism. The resulting air pocket disrupts and reroutes the flow of water up the tree, and after a critical mass of these embolisms, the tree dies.[1]

A boundary layer of non-moving air molecules surrounds the surface of the plant, and the size of this layer changes the rate of transpiration. A thinner boundary layer means water vapor has less resistance as it leaves the stomata. Higher levels of wind can replace this boundary layer more quickly, resulting in faster levels of transpiration.[2] This is especially evident in deciduous trees in the fall, since trees exposed to more wind tend to change color earlier and lose their leaves faster. It

[1] John S. Sperry and Melvin T. Tyree, "Mechanism of Water Stress-induced Xylem Embolism," *Plant Physiology* 88, no 3 (1988): 586.
[2] Park S. Nobel, *Physicochemical & Environmental Plant Physiology, 2nd ed,* (San Diego: Academic, 1999), 271-3.

is more difficult to see in conifers like the Ponderosa.

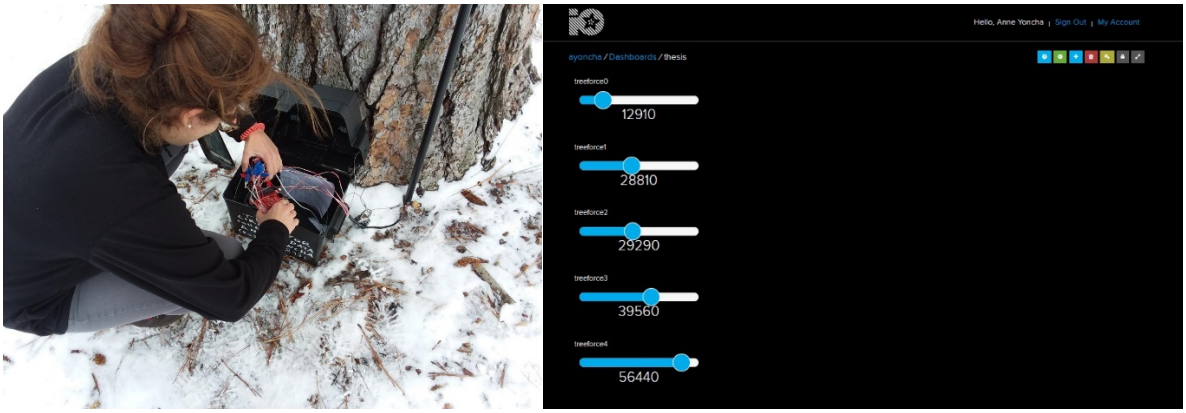
Because wind speed generally increases further from the ground, I became curious whether similar circuitry and sensors as the ones I used in Lincoln could pick up on what I expected to be some very subtle changes. Instead of working with a stand of ten trees, I wanted to gather data from several points on the same one. I climbed into the canopy of the Ponderosa I call my "thesis tree", and installed five analog flex sensors, which at 4.5" in length bend similarly to a needle.

Flex sensor wired to Ponderosa pine (image: Brock Mickelsen)

Each sensor is attached to two wire leads which run down the trunk of the tree back to ground level, making a circuit. As wind bends the sensor, the resistance of the circuit changes. At the base of the tree, I designed a ventilated, waterproofed lockbox to house the electronics for what I call the "input circuit". This circuit is run by a Raspberry Pi single-board computer. An MCP-3008 chip[3] translates the analog signal from the flex sensors into a digital one which can be processed by the computer. A Python program[4] tells the Pi when to read the signal from each sensor—every 5 seconds—and what to do with it—send it, via wi-fi connection, to one of 5 feeds I set up on a cloud data hosting site, Adafruit IO.

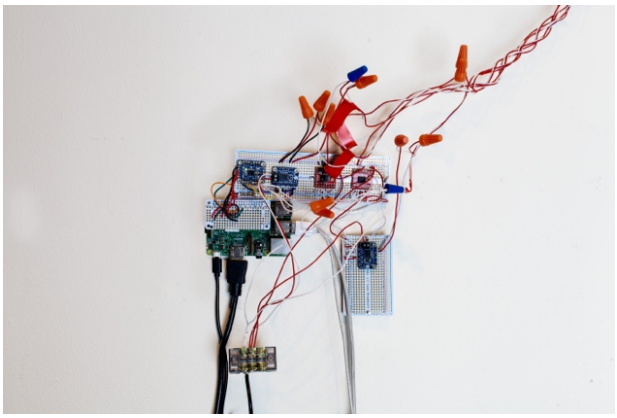
[3] Kattni Rembor, "MCP3008 – 8-Channel 10-Bit ADC with SPI Interface." *Adafruit Learning System.* Accessed May 1, 2019. https://learn.adafruit.com/mcp3008-spi-adc/overview.

[4] See input code, designed in collaboration with Brian Givens, in Appendix A.



Assembling the input circuit at the base of the tree (left), and Adafruit IO data-hosting interface, each slider representative of data from one sensor (right)

Inside the gallery is a counterpart "output" circuit. Another Pi computer is connected to a TLC-59711 motor controller chip.[5] Wire leads run from these motor controllers to each of the five fans in the gallery. Another Python program[6] tells this second Pi computer to connect to Adafruit IO, the data hosting site. The integer readings on each feed on Adafruit IO, which change every five seconds, are then transmitted to the motor controllers. Changes in the feed translate to changes in voltage, which result in changes in the velocity of each fan.



Second Wind *output circuit (image: Brock Mickelsen)*

Also inside the gallery are structures which "materialize" the data. Five 12-volt fans have been disassembled and soldered to leads which run to the motor controllers. Each fan interacts with an 11' tapered vellum structure, which is suspended from the ceiling and able to swivel in reaction

[5] Bill Earl. "TLC5947 and TLC59711 PWM LED Driver Breakouts." *Adafruit Learning System.* Accessed May 1, 2019. https://learn.adafruit.com/tlc5947-tlc59711-pwm-led-driver-breakout?view=all.

[6] See output code, designed in collaboration with Brian Givens, in Appendix B.

to moving air. The trapezoidal form of the vellum is meant to be reminiscent in form and function to a sail. The vellum is sandwiched between rounded strips of pine, which reinforce the angular shape of the panel as it contacts the gallery floor at one pivot point. On each panel is a narrow strip of graphite drawing combined with ink from the needles of the tree—the only evidence of the hand-made mark and one of the few links to the specific tree.

Second Wind *installed in Gallery of Visual Arts (image: Brock Mickelsen)*

At the opening reception, collaborator Jay Bruns used Lumen, a video synthesizing software, to allow viewers to make visual modifications to an image of Ponderosa bark I photographed while climbing the tree. This component was intended to function as a counterpart to the other structures in the gallery: while the fans and sails translated external forces on the tree into the gallery, MIDIsprout and Lumen worked instead with internal forces such as moisture content changing conductivity.

A viewer using Lumen

The Ponderosa is an evocative species because of its ubiquity in the Missoula area; its reddish, interlocking bark; and its feathery needles. The Ponderosas planted on campus, however, have an even more resonant story. Because of the periodic scouring of the surface of glacial Lake Missoula during historic freeze-thaw cycles, natural forests were not able to develop in the area that is now part of the University of Montana campus. The ranks of Ponderosas extending toward the Clark Fork River were planted as a memorial allée in honor of those who died in World War I.[7] Examining wind, and its associations of breath and life, in relation to a memorial has been an intriguing layer of meaning to explore.

***Personal and Conceptual Goals for* Second Wind**

I wanted to create an opportunity to engage with the tree, becoming familiar with physiological processes impacted by wind in all Ponderosas, learning the history of this particular tree, and spending several days observing a pine bough while generating the images. As critic Collingwood argues, doing art can teach us something we can't learn in any other way.[8]

I aim for viewers to have a parallel, though not identical, experience. They may read the rendered imagery as organic, plant-based, and then realize it referencdes a tree. I hope viewers are be able to determine that wind level in the gallery is inconsistent by observing minute changes in the angle of the panels and the sound of the motors, and by feeling the moving air as they walk past the fans. By isolating the force of the wind from the totality of forces enacted upon the tree, and by resituating it inside the gallery, I hope to help viewers focus on it with more clarity. Perhaps these acts of noticing could create a similar engagement for viewers contemplating the piece that I had in creating it.

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[7] Ibid.
[8] Aaron Ridley, "R. G. Collingwood", *Key Writers on Art: The Twentieth Century,* (New York: Routledge, 2003), 77.

2. Why a Tree?

The Many Meanings of a Tree

The tree as a symbol has rich context. The tree of knowledge evokes temptation, wisdom, and a fall from paradise which could be reconceived as a shift from classical naivete to romantic longing. Trees connote rootedness, strength, steadiness, long life, and delayed gratification. Within ecosystems trees provide sustenance, shade, habitat, shelter, and can function as indicators of system-wide health and changes. We find in trees a source of energy, fuel, building material. Trees sequester carbon and prevent erosion, host fungi, and provide nutrients when decomposing. Family trees help visualize lineages and linkages. When Austrian-Israeli philosopher Martin Buber wrote in 1923 about the distinction between "I-Thou" and "I-It" dialogues, his first example of a "Thou", or a being with which the "I" recognizes a connection and interdependence, was a tree.[9] Perhaps it is these complex, overlapping, and conflicting associations with the tree that make it a fertile area for exploration in contemporary art. Below are a few examples of recent artworks which situate actual trees in unfamiliar settings to translate some of these meanings.

Death of a Tree: Brandon Ballengée & Robert Smithson

In 2012, artist and biologist Brandon Ballengée resituated a dying tree into the gallery, its spindly and arthritic-looking branches and roots spidering through the regular geometry of the gallery space. Ballengée used contact microphones to pick up changes in the tree's surface as its body slowly dried, amplifying invisible dynamics occurring within the tree even after death.[10] This visceral experience of the slow death of another species, a subtly changing memento mori, forces viewers to confront the passage of time and the fact that we humans die in the same way.

Ballengée directly references Robert Smithson's 1969 work, *Dead Tree*, which similarly

[9] Martin Buber, and Ronald Gregor Smith, *I and Thou,* (Edinburgh: T. & T. Clark, 1953), 7.
[10] Brandon Ballengée, *Dying Tree,* 2012, Domaine de Chamarande, France, https://brandonballengee.com/dying-tree/.

resituated the carcass of a 40' tree.[11] Where Ballengée used sound to amplify internal processes of the tree's death, Smithson used mirrors to reflect upon the tree, both literally and figuratively. This work was one of a series of "displacements"[12] in which mirrors generated a representation and abstraction of the reference, placing it in conversation with itself. Smithson's mirrors evoke a division between the tree itself and our ability to see, experience, and understand it.

Dying Tree *by Brandon Ballengée (image: brandonballengee.com, left), and* Dead Tree *by Robert Smithson (image: researchgate.net, right)*

Rebirth from a Tree: Mark Dion

In an 80-foot long glass-walled building in Olympic Sculpture Park, Mark Dion put a hemlock tree on life support. The tree fell in a protected area west of Seattle in 1996, and Dion transported it into the gallery a decade later, birthing the installation *Neukom Vivarium*. Dion is adamant that the piece is not just about the tree (which while decomposing is also hosting a bevy of other, smaller life forms from ferns to fungi), and not just about the space which frames it (which references a greenhouse, and creates a closed-circuit terrarium which artificially houses and controls a natural process, and which probably also has a particular organic smell).[13] While the

[11] Robert Smithson, *Dead Tree,* 1969, Kunsthalle Dusseldorf, Germany, https://www.robertsmithson.com/sculpture/dead_tree_300.htm

[12] Johannes Stückelberger, "Mirror Reflections: Robert Smithson's Dialectical Concept of Space," *Canadian Art Review,* 31, no 1/2 (2006): 92.

[13] Mark Dion, "Neukom Vivarium", Interview with Art21, *Art21*, accessed May 1, 2019, https://art21.org/read/mark-dion-neukom-vivarium/

piece creates a rich, sensory experience,[14] it is about systems, he says. Pulling the tree out of its original location impacts the ecosystem with its absence, while the requirements needed to sustain the nurse log in a man-made space are complex and energy-intensive—and perhaps also futile and absurd. *Neukom Vivarium* is part of Dion's larger body of work examining the intricacy of natural systems, our place within them, and our inability to completely make sense of them.[15] Here the tree has a taxonomic and hierarchical implication.[16] It references the increasing evolutionary complexity in our classification systems, which often culminates with humankind, but subverts that system by turning it on its side.

Neukom Vivarium *by Mark Dion (image: Art21)*

Structures which Subvert the Tree as Icon: Natalie Jeremijenko

In 1999, Natalie Jeremijenko planted six maple trees outside the Massachusetts Museum of Contemporary Art. The trees weren't, however, planted in the ground. They were suspended by telephone poles and cables, overhead and upside down. Over the years, evidence of the trees' growth toward the sun began to show in unnatural-looking curves in their trunks and branches. In this piece, *Tree Logic*, Jeremijenko draws our attention to the symbol of the tree and how natural

[14] Lisa Graziose Corrin, "Mark Dion's Project: A Natural History of Wonder and a Wonderful History of Nature", *Mark Dion*, (London: Phaidon, 1997), 52.
[15] Ibid., 38.
[16] Norman Bryson, "Mark Dion and the Birds of Antwerp", *Mark Dion,* (London: Phaidon, 1997), 93.

forces like gravity and light have contributed to that iconography[17] by literally turning the system on its head. Since we are jarred away from seeing the tree as a static symbol, we must reconsider it as a dynamic entity. Viewers can experience the physicality of the piece at any time, but the meaning unfolds only over time, questioning the "nature of the natural."[18]

Tree Logic *by Natalie Jeremijenko (photo: Rainy Day Magazine)*

The Place of Second Wind *in this Conversation*

Inspired by the work described above, I created *Second Wind* to draw upon the familiar icon of the tree, translate it into the gallery, and mediate our experience with it. I hoped also to experiment with ways of framing the tree, placing it in a new context to help viewers engage with it in a different way. Instead of relocating an actual tree, I experimented with creating structures which would allow invisible data to materialize inside, and away from, the tree—discussed below.

[17] Laura Steward Heon and John Ackerman, "Natalie Jeremijenko," *Unnatural Science: An Exhibition, Spring 2000 – Spring 2001,* (North Adams: MASS MoCA, 2000), 21.
[18] "Natalie Jeremijenko: Tree Logic," *MASS MoCA,* accessed May 1, 2019, https://massmoca.org/event/natalie-jeremijenko/.

3. Structure of *Second Wind*

While designing *Second Wind*, I made a series of decisions designed to evoke a specific aesthetic experience, and to guide viewers to some of the conclusions mentioned above. I used rectilinear panels to materialize the wind data. These panels are uniformly constructed and evenly spaced, meant to reference our attempts to structure knowledge and make meaning.[19] I hope a viewer's experience of the verticality of the panels, and their larger-than-human scale, is parallel to the experience of the height of a tree, and that as a viewer looks upward their eyes trace the direction of growth of the tree and the movement of water within it.

The same trapezoidal shape is repeated in each panel. The consistent structure of each panel ideally allows the piece to highlight subtle differences in data. Since we know the panel structure is constant, any movements can be read as a result of the variable—the wind.

The panels are suspended from a pivot point in the ceiling, a tension which I intended to reference the force of transpiration. The wire leads from the fans run up to the same points, hopefully creating a sense of counterbalance between wind and panel. The tapered edge of each panel meets the floor of the gallery at one dramatic point, and the upward force of the floor on the vellum creates a subtle compression in the surface of the panel. I hope these paired forces of tension and compression evoke some of the dynamics at work inside the tree. Each pairing of fan and panel references one specific height on the tree, one data point. To make sense of these data points, we string them together, interpreting trends, finding a line of best fit.

While I designed the structural language of *Second Wind* to prompt viewers to build a narrative from the data they observe, I hope the piece also leads to questions about those narratives and our attempts to systematize these natural phenomena, which I will discuss further below.

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[19] Janetta Rebold Benton and Robert DiYanni, *Arts and Culture: An Introduction to the Humanities, 3rd ed.,* (Upper Saddle River, NJ: Prentice Hall, 2008), 631-2.

3. *Second Wind*'s Response to Minimalism

American art critic Barbara Rose describes minimalism as a counterpart to the clutter of pop culture and commodification. She characterizes the movement as insistent on aloofness and refusal to refer outward,[20] a form with no referent. With this reading, *Second Wind* is decidedly not minimalist, since it directly references a specific entity and real, measurable processes.

Rose points out a few other aspects of the minimalist movement, though, which are important to discuss in relation to my piece. She addresses a tension between two trends she sees in the movement—the search for an absolute truth and universal experience which transcends specificity, and conversely the denial of the existence of that kind of absolute.[21] This tension parallels our method of scientific inquiry, which engages in an ongoing quest to substantiate theory and approach fundamental truths about our universe, but which must also acknowledge that the path to this kind of absolute truth is asymptotic.

Rose notes that minimalist artists focus on the importance of experiencing the "face value" of objects. This focus is meant to heighten awareness of materiality, emphasizing a viewer's physical experience in the here and now.[22] It is possible to interpret this kind of materiality as performative. Though we as an audience at the theatre know that planning, writing, casting, and practicing undergird the experience of theatre, we willingly suspend our disbelief to engage with the unfolding world of the play. We experience the materiality of the play, in the here and now, the way viewers experience the materiality of the minimal objects Rose writes about.

Modernist art critic Michael Fried critiques this theatricality because the artwork sets up a scenario which depends on the presence and engagement of a viewer.[23] The problem with this scenario is the assumption that the viewer, or the audience, is the subject, and the artwork he is

[20] Barbara Rose, "ABC Art," *Art in America,* (October – November, 1965), 281.
[21] Ibid., 277.
[22] Ibid., 281.
[23] Michael Fried, "Art and Objecthood," *ArtForum,* (June 1967), 125.

viewing is the object. The theatrical artwork leads, for Fried, not to a unified experience of the here and now, but to an increasing distance between viewer and object.[24]

I am interested in exploring these ideas of theatricality in the context of *Second Wind*, particularly through the piece's almost choreographic presentation of data, and the viewer experience of the performed data. The installation of *Second Wind* creates a world based on the tree outside, yet distinct from it. The work requires a willing suspension of disbelief—viewers know the gallery component of the piece is an analogue of the tree, a translation, and must extrapolate from that to make sense of the movements of the panels.

The point at which each panel contacts the ground makes a drawing the whole time, a choreographed dance determined by wind data. It emphasizes the actors—the panels and fans—but does not record any representation of the drawing they create. This idea of action with no record is one I find especially compelling in relation to data collection, since we usually conduct research for future analysis. Perhaps this piece, which translates the ephemeral motion of air into data only to translate it back into that same ephemeral motion of air, may evoke the passage of time in a way which encourages viewers to more carefully contemplate and more fully engage with the tree.

[24] Ibid., 126.

4. The Hand-Made Mark

Linking the hand, data, and perception: Janine Antoni

In 1993, Janine Antoni began a performance, *Slumber*, which transformed the ephemeral experience of her sleep cycles into sculpture. While she slept, she used an EEG machine to record her eye movements and REM cycles. During the day, she wove that data into a blanket—and by night, she slept under that blanket. The data, which formed something like a sine curve on the blanket, was echoed by the swooping lines of the threads from the loom overhead. Antoni's performance layers the natural and mechanized, analog and digital, personal and public.[25]

Slumber *by Janine Antoni (image: janineantoni.net)*

I looked to several aspects of Antoni's work as I conceptualized *Second Wind*. Aside from her material translation of data, I was drawn to her use of line—the threads connecting the components of her piece, as well as the strong links between her materials and concept. I began thinking about how I could use line to create an initial aesthetic experience, and what mark-making material could anchor that experience to the tree conceptually.

Iron gall ink, a traditional recipe for indelible ink made from tannic galls (cocoon-like structures harvested from the underside of oak leaves), ferrous sulfate, and gum arabic,[26] could be

[25] Heon, *Unnatural Science,* 47.
[26] Cynthia Karnes, "How to Make Ink – Recipes and Instructions," *The Iron Gall Ink Website,* accessed May 1, 2019, https://irongallink.org/.

adapted to use pine needles as the tannic component,[27] so the mark-making tool could come from the tree itself.

Pine needles from thesis tree (left) were fermented, boiled, and mixed with gum arabic and ferrous sulfate (dark liquid and green salt (center), detail of rendering on vellum paper (right, image: Brock Mickelsen)

While Antoni's linework, woven in a graphed wave, kept her data encoded, I hoped I could use my linework to make my data more legible. I considered this especially important since the vellum panels enacting the data were so far removed from the tree. I photographed views of the canopy from the height of each sensor, documenting the increase in branch and needle density with height. I then rendered slivers of these photographs—crops in the same dimensions as the flex sensors to evoke the specific window revealed by the data—on the panels.

Using graphite alongside the ink, layered above and below it, allowed me to make an intimate mark indicative of the intimate scale I was using to observe the tree. It also evokes erasure, impermanence, and the potential for leaving traces—a quality I found appealing when thinking about the ephemeral nature of the data, and the tree's history as a memorial.

Not all the aesthetics in *Second Wind* were so closely controlled, however. In fact, much of the aesthetic experience was unregulated, at least by me.

[27] Altered iron gall ink recipe used in *Second Wind* in Appendix C.

5. Poststructuralism

While the structures, arrangement of space, and rendering choices in *Second Wind* are carefully considered and orchestrated, those structures are acted upon by unregulated conditions. They are altered, manipulated, and interrupted by natural processes—specifically wind. In this case, wind data provides a commentary on the structure, and reveals information which is not revealed by the structure. Second Wind follows closely in the tradition of Stacy Levy and Patrick Zentz, who work sculpturally to visualize wind data.

"Little Science": Stacy Levy

In *Seeing the Path of the Wind*, Stacy Levy installs dozens of small organza flags evenly spaced on the floor. Fans communicate with an anemometer and other weather station tools to make changes in the direction of the wind outside visible via the flags inside. Critic Laura Heon describes Levy's work as "little science", operating in a space where the data can be playful, exploratory, leading to a non-monolithic, personalized experience.[28] Levy also uses accessible and recognizable materials which democratize the process of gathering and disseminating this data, and make it possible to engage in a new way with the mechanics behind it.

Seeing the Path of the Wind by Stacy Levy (photo: MASS MoCA)

[28] Heon, *Unnatural Science,* 12.

Data Visualization to Engage with Place: Patrick Zentz

Montana-based artist and University of Montana School of Art alumnus Patrick Zentz has been working this way for decades. His three-piece sculpture, *Trio*, which became part of the permanent collection of the Missoula Art Museum (MAM) in 2011, uses sensors which translate wind data from outside the gallery into analog signals for motors. The motors generate tone and rhythm on three instruments in the gallery, so that wind becomes sound.

Zentz talks about the interaction of wind with the natural instrumentation of a place, and how that interaction can help us recognize and understand a site.[29] That kind of recognition is important, he says, because it allows us not just to understand individual lifeforms on the site, but the complex web of ecological relationships which bind us to places as well.[30] Zentz abstracts this organic interaction, translating it through programmed chips and sensors to precisely-designed kinetic sculptures in the gallery, so we can experience the natural phenomenon in a different way.[31]

In an artist talk at the MAM, Zentz says that the goal of the work, ultimately, is "about being enchanted with the world."[32] This phrasing hearkens back to painter and critic Suzi Gablik and the reenchantment project she discussed in 1991,[33] which argued for a non-commodifiable contemporary art which would allow us to refocus on the complex mystery of the world around us. Perhaps Zentz's work materializing ephemeral data in a new framework can provide a concrete solution to Gablik's concern about our lack of engagement with the world.

Part of this reengagement comes from Zentz's means of translating the outside to the inside. He acknowledges the absurdity, in one view, of looking to art to experience something like wind,

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[29] "Patrick Zentz: TRIO," *Missoula Art Museum,* posted February 19, 2015, accessed May 2, 2019, https://www.youtube.com/watch?time_continue=4&v=iO1_QYutqXk

[30] Regina Hackett, "Zany Zentz Sculptures Harness the Wind," *Seattle Post-Intelligencer,* accessed February 28, 2019, www.suyamaspace.org/assets/uploads/installations/press_zentz_seattlepi_052899.pdf.

[31] Robin Updike, "Poetic Sounds that are Here with the Wind," *Seattle Times,* May 28, 1999, accessed February 28, 2019, C5.

[32] "Patrick Zentz: TRIO," *Missoula Art Museum.*

[33] Suzi Gablik, *The Reenchantment of Art,* (New York: Thames and Hudson, 1991), 181.

which could just as easily be felt by taking a step out the door. But the problem is more complex than that. He sees a larger issue around how we understand the outdoors—or how we increasingly do not—as a result of a dichotomy we created by building structures and creating indoor spaces.[34] The spaces which allow us to survive—which protect us from the elements and provide us comfort—also change the character of the way we survive, distancing us from the outdoor world in a way which is mostly invisible and subconscious. Data, Zentz argues, is a potentially powerful new means to look at the natural world, and coding can provide a way to "focus" that "lens."[35]

Components of Trio *by Patrick Zentz (image: Montana Arts Council)*

The Slipperiness of Air in Second Wind

I'm especially intrigued by Zentz's efforts to refocus that lens on air, which he calls a "slippery medium."[36] Air is slippery to see—we can really only perceive its impact on other objects, its trace on water, or its manifestation as heat waves. It is also slippery in direction, constantly undergoing slight oscillations.

[34] Regina Hackett, "Zany Zentz Sculptures Harness the Wind."
[35] Patrick Zentz, "Art and Science – Together at Last: Patrick Zentz at TEDxBillings," *TEDx Talks,* published March 21, 2014, accessed May 2, 2019, https://www.youtube.com/watch?v=e_K69r4EGBk.
[36] Ibid.

Post-structuralist philosopher Jacques Derrida wrote in the late 20th century about the "slipperiness of meaning."[37] Language, he says, is an imperfect system defined by context, and it is important to question the systems we use to communicate knowledge to determine who creates these frameworks, what interests are at play, and who stands to gain.

Similarly, the movement of the vellum panels in *Second Wind* is dependent on a force outside the structure. The congruity of the panels is belied by the pivot points and their swiveling motion. Changes in the velocity of the fan can cause literal reversals of the vellum structures, interrupting their regular placement, and changing the ways viewers interact with the space. I hope this reversibility references Derrida's ideas of structural slipperiness. I also hope the spaces between the panels and the blank spaces on the vellum reference the incompleteness of our data, and our means of collecting and understanding it.

While Zentz's and Levy's ideas about engagement with place have been instrumental to my recent work, I still consider myself more a painter than a sculptor. The traditional act of painting, which provides my personal translation of the experience of place and data, is a place where our work diverges.

[37] Terry Barrett, *Why Is That Art?,* 2nd ed, (New York: Oxford UP, 2012), 169.

6. Why is Data such a Big Deal?

German art critic and philosopher Boris Groys draws a sharp line between science and religion, and one important tool he uses to draw that line is data. Science, he says, is an active process of making truth which requires engagement with changing conditions and is constrained by need for substantiation. It is a public process which is supposed to progress, building knowledge over time. Religion, on the other hand, has the freedom to operate more passively, because private decisions based on belief do not have the same constraints as science. He warns against the potentially static and consumptive aspects of this kind of belief.[38]

Digital data, for Groys, provides a timely if slightly confusing means to look at this distinction. Groys likens digital data to a microbe—it is capable of infinite reproduction and organic movement. It can preserve itself indefinitely, generating a potentially infinite number of identical copies. He describes data as stable and immortal.[39] Data represents the eternal, and our drive to collect it is indicative of our yearning to capture some sliver of that endlessness.

However, there is one notable problem with this interpretation of data, which Groys illustrates. We can only see digital files by opening them, looking at the image for example. The image, he says, is a representation of the file itself, while the data which backs the image remains hidden.[40] Every time we open an image file, run a code script, or perform a play, we are materializing the invisible. This performance or enactment may provide a visceral experience of something like the invisible data, the coded instructions, the script—but it can never, according to Groys, remain true to the original.[41] Every enactment becomes a rendition which is specific to its context. It can represent the original, but it can never exactly repeat the original.

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[38] Boris Groys, "Repetition versus Progress," *Now is the Time: Art & Theory in the 21st Century.* Terry Eagleton et al., eds. (Rotterdam: Nai, 2009), 27.
[39] Ibid., 27.
[40] Ibid., 27.
[41] Ibid., 28.

For Groys, art cannot exist in the sacred religious sphere, because artists are incapable of true repetition.[42] However, to appreciate a work of art, a viewer makes an aesthetic judgement which is based on an intuitive feeling. Groys notes that this initial reaction is not based on rigorous inquiry and in fact is much more akin to a "leap of faith."[43] This distinction becomes more interesting in the context of Walter Benjamin's lament that, in our age of increasing technological capability, the uniquely powerful and human "aura" in any work of art may have vanished.[44] Groys seems to be not only cautioning against the dangers of the endless same-ness of the stream of data, but also noting that any manifestation of that data is capable of providing something new.

By creating repetitive structures which both react to data and contain hand-made marks indicating my own interpretation of this data, I hope to engage with questions like these in *Second Wind*. I hope the viewer's initial aesthetic response to the vaulted, illuminated panels may be a connection to panels of stained glass, and the gallery as a space reminiscent of a chapel, though a version of a chapel with data-driven, scientific underpinnings.

[42] Ibid., 26.
[43] Ibid., 23.
[44] Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction," *Marxism and Art: Writings in Aesthetics and Criticism,* Berel Lang and Forrest Williams, eds, (New York: David McCay, 1972), 284.

7. How Science Took the Lead Over Religion, and What this Means for Art

Critics like Lynn Gamwell and William Dunning have studied the links between science, religion, and art through the ages, tracing parallel trajectories and practices. Gamwell frames the Enlightenment as a particularly notable time when tradition, religion, and mysticism gave way to rational inquiry and secularism. This occurred in large part in reaction to the dissolving cultural belief in the fixity of the Great Chain of Being into the dynamism of evolution.[45] Dunning notes that this transition was espoused simultaneously by artists and scientists, as thinkers in both fields worked to reconfigure conventions for seeing and understanding their world in this new context.[46]

Science in many ways became a new religion, as became evident in the art of the time. Joseph Wright of Derby's painting known as *The Orrery*, for instance, depicts a lecturer using a lamp to approximate the position of the sun in the solar system. Wright of Derby uses dramatic illumination reminiscent of Caravaggio's paintings from a century earlier—but in this case, the almost spiritual effect of the lighting is repurposed for a new, secular understanding of the world.[47]

The Orrery *by Joseph Wright of Derby, 1766 (photo: BBC, left), and*
Supper at Emmaus *by Caravaggio, 1601(photo: National Gallery, London, right)*

While Derby's painting evokes a sense of wonder, it is worth considering what we lost in

[45] Lynn Gamwell, *Exploring the Invisible: Art, Science, and the Spiritual,* (Princeton: Princeton UP, 2002), 9-11.
[46] William Dunning, *The Roots of Postmodernism,* (Englewood Cliffs, NJ: Prentice Hall, 1995), 66.
[47] Bradley Allen, Conversation, University of Montana, October 31, 2018.

this transition to empiricism. Canadian philosopher Charles Taylor wrote in 1991 about the malaises we feel as a society which mourns the shared community experience of the pre-industrial world.[48] Decades earlier, Martin Heidegger warned that we are losing touch with the mystery of our own being and our interconnectedness with other beings, both human and non. He saw a parallel shift in technology—from a focus on "techne"[49] which was able to reveal the hidden to create significant works which shape and are shaped by culture, for instance the Greek Parthenon[50], to "enframing" with a focus on efficiency, utility, and output.[51] As the same efficient modes of production impacted the art world, artists and critics were forced to reconsider questions of originality and artistic genius—whether art could still have the disclosive power that Heidegger and Benjamin discussed, or whether the development of art had come to an end.

Ethical issues around technology have become an even more pressing issue in what University of Montana environmental philosopher Christopher Preston calls the "Synthetic Age". He notes humans' increasing capacity to create fundamental material changes in our world. Through nanotechnology, we can literally rearrange the atoms of natural substances so that the building blocks of materials around us are increasingly manufactured rather than natural.[52] At a global scale, geoengineers consider largescale interventions to counteract climate change, attempting for instance to reduce global temperatures by injecting sulfur dioxide into the atmosphere to mimic the cooling effect of volcanic ash.[53] Preston urges us to consider the ethical implications of actions like these. The field of restoration ethics developed in the past few decades to address questions of how to act when the urgency of the situation seems to demand intervention,

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[48] Charles Taylor, *The Ethics of Authenticity,* (Cambridge: Harvard UP, 1991), 10.
[49] Martin Heidegger, "The Origin of the Work of Art," *Martin Heidegger: Basic Writings,* David Farrell Krell, ed, (San Francisco: HarperCollins, 1993), 184.
[50] Ibid., 167.
[51] Ibid., 189.
[52] Christopher Preston, *The Synthetic Age: Outdesigning Evolution, Resurrecting Species, and Reengineering Our World,* (Cambridge: MIT, 2018), 32-3.
[53] Ibid., 121-2.

but the consequences of human intervention are largely unknown and unpredictable.[54]

If we can't return, societally, to religion, what is left to bring us together, to elevate the human spirit, and to help us make sense of the changing world and our place within it? University of Montana philosophy professor Albert Borgmann posits that the land, especially in the United States, can provide a locus for focal practice and engagement.[55] Perhaps the intersection of science and art can provide a fruitful way of re-focusing on the land and our relationship to it. This relationship may help us determine ways to ethically navigate new technological challenges.

[54] Ronald Sandler, "Global Warming and Virtues of Ecological Restoration," *Ethical Adaptations to Climate Change: Human Values of the Future,* Allen Thompson and Jeremy Bendik-Keymer, eds., (Cambridge: MIT, 2012), 77.
[55] Albert Borgmann, "Authenticity and the Meaning of Life," lecture, The University of Montana, Missoula, MT, December 5, 2017.

8. Science and Art Today

One commonly held view among many writers who discuss links between science and art is that science serves as an inspiration for art. Neil deGrasse Tyson even problematically titles the prologue for Gamwell's book: "Science as the Artist's Muse."[56] James Elkins notes, in contrast, that art and science are two disciplines working at the edge of what is possible to see and represent. Though the two disciplines work in similar ways, different narrative styles can make the them seem more disparate than they really are.[57]

Art can shape the way we conceive reality, change our areas of focus, and suggest new ways of looking and understanding which open the door for new lines of scientific inquiry. For instance, our conceptualization of "nature" and what it means to be "natural" has changed. Perhaps this is a result of changes in how we use language, how we use signs and signifiers. These sorts of changes can be brought about by art.

Jedediah Purdy considers our changing ideas of nature through a legal lens, considering how our seemingly amorphous conceptions have very real and tangible impacts on the way we use land. Historically, he notes that Wordsworth viewed nature as teacher, while John Stuart Mill's conception of nature, when applied to politics, was prejudicial.[58] In the American cultural conception of the frontier and westward expansion, nature exemplified a sense of hope, promise, abundance, and limitlessness—a construction of course predicated on colonialism. Economically, nature can be equated to the "spontaneous order" of the free market.[59] The wildness of nature historically often indicated not a set of ecological relationships but a moral testing ground, a dark and chaotic desolation through which one traveled to prove strength and attain clarity.[60] Finally the

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[56] Neil deGrasse Tyson, "Foreword: Science as the Artist's Muse," *Exploring the Invisible*, 6-7.
[57] James Elkins, *Six Stories From The End Of Representation: Images In Painting, Photography, Astronomy, Microscopy, Particle Physics, And Quantum Mechanics, 1980–2000*, (Redwood City: Stanford UP, 2008), 1-10.
[58] Jedediah Purdy, *After Nature: A Politics for the Anthropocene,* (Cambridge: Harvard UP, 2015), 13.
[59] Ibid., 279.
[60] Ibid., 52.

idea of "second nature" recalls a certain expertise and virtuosity, while also implying "artifice, storytelling, and imagination"—by definition it cannot be primary or original.[61] Purdy emphasizes that, with the onset of the Anthropocene, humans' indelible impact on the world at every scale has erased traditional distinctions between natural and artificial.[62] Drawing this line between ourselves and the natural world, between our technology and natural technology, is no longer logical or helpful. The world, he says, is a "world we have made."[63]

If we can think about nature in this way, it may be easier to consider Preston's ethical warnings and Borgmann's concerns about engagement with place. Landscape art can help us more expansively imagine our land and more powerfully feel an affinity with it, helping inform us about our actions and their ecological impacts. To examine this idea, we need first to define "landscape art".

[61] Ibid., 95.
[62] Ibid., 15.
[63] Ibid., 3.

9. On Landscape

It may be helpful to consider how, like our shared conceptualization of "nature" and perhaps in tandem with it, our conceptualization of "landscape art" has undergone shifts. John Quincy Adams believed that Americans could become more virtuous through repeated exposure to the sublime visual elements of the landscape.[64] Likewise, Thomas Cole, Asher Durand, and other members of the Hudson River School emphasized that landscape art did more than simply copy a scene onto a page—it evoked, for artist and viewer, a sense of authenticity and discernment about the place which extended beyond a naturalistic portrayal, providing a sense of "insight."[65] The act of looking required to make these paintings, and the act of repeatedly looking at them as viewers, would theoretically lead to a more correct moral and philosophical experience.[66]

Merced River, Yosemite Valley *by Albert Bierstadt, 1866 (image: Metropolitan Museum of Art)*

Lynn Gamwell notes shifts in artists' conceptualizations of the natural world alongside unsettling and seemingly irreconcilable discoveries in particle physics in the 1900s.[67] As scientists explored the world at increasingly small scales, artists too zoomed in on the microscopic building blocks which make our world. Exalted and elevated depictions of nature's elegance gave way to

[64] Ibid., 111-2.
[65] Ibid., 114.
[66] Ibid., 283-4.
[67] Gamwell, *Exploring the Invisible,* 265.

contemporary landscapes which were increasingly unsettling, mysterious, and non-linear.[68] Instead of attempting to evoke a constant, universal aesthetic, artists highlighted the tenuous and vulnerable relationships they observed.[69]

In the mid-twentieth century, land art arose as a movement which situated works not in the comfortable and expected framework of the gallery, but in rugged and remote landscapes where they were framed only by more vastness. The works emphasized both human technical ingenuity through the massive efforts made to construct them—similar in some ways to the coming-together needed to build Heidegger's example of disclosive art, the Parthenon—and human smallness through our incapacity to fully comprehend the piece or its surroundings. Land art questioned whether the art was found in the fabricated work, or the space to which it called our attention.[70]

Perhaps also unnerving is the change in how these works are made. Thinking back to Heidegger's *techne*, the sense of skill and virtuosity has often been lost. How can the average viewer understand the passage of the hand in placing the six thousand tons of basalt in Robert Smithson's *Spiral Jetty*, or the fabrication of massive concrete pipes in Nancy Holt's *Sun Tunnels*? Certainly there is no evidence of the human hand in the changing angle of the sun throughout the year in James Turrell's pieces. The separation of maker from art object, and the increasing obscurity of the technology needed to make it, may be evocative of our increasing detachment from place and one another.

Several contemporary artists are working in a more intimate, though still data-driven, way. Edward Burtynsky makes panoramic photographs documenting landscapes disturbed by human intrusion. Series like *Tailings* document the impact of extractive industries on rivers. While it is possible to look at Burtynsky's photographs formally, appreciating the stunning ribbons of orange

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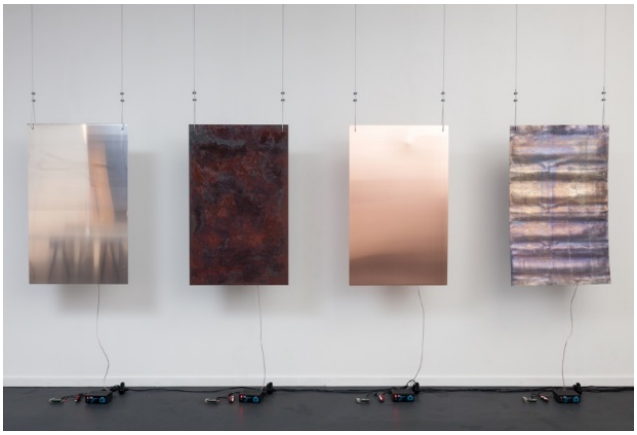
[68] Purdy, *After Nature,* 230.
[69] Siân Ede, *Art & Science,* (New York: I. B. Tauris, 2015), 161-78.
[70] Jack Flam, "Introduction: Reading Robert Smithson," *Robert Smithson: The Collected Writings,* (Berkeley: University of California, 1996), xiv.

running through monochrome arid landscapes, viewers know the work has a referent. Burtynsky here questions the difference between natural and unnatural disasters, while also asking us to come to terms with the fact that we have found beauty in a ruined landscape.

Nickel Tailings #35 *by Edward Burtynsky, 1996 (photo: edwardburntynsky.com)*

Sculptor Brian House also looks at mining pollution in his Animas River project. He collects real time data on water flow and translates it into the gallery, where it changes the frequency of vibrations of a series of metal panels, generating a constantly changing chord which reverberates through the gallery. The panels are made of metals exceeding EPA regulations in the Animas river. These rectilinear forms recall in form the sculptures of Richard Serra and Donald Judd—but again have a direct material and conceptual referent. As in Burtynsky's work, viewers here are asked to reconcile the aesthetic resonance of the sounds they hear, and the pleasing order of the forms they encounter, with the ongoing disaster which underlies them and is reverberating in a less controlled way.[71]

[71] Susan Froyd, "Myhren Gallery's *Storm Warning* Heats Up the Debate Over Climate Change," *Westword,* published April 11, 2017, accessed May 2, 2019, https://www.westword.com/arts/storm-warning-offers-straight-talk-about-climate-change-at-vicki-myhren-gallery-8959705.



Animas *by Brian House, 2017 (photo: brianhouse.net)*

Can we define contemporary landscape as making the problematic aesthetic, or making the aesthetic problematic? Perhaps we need this kind of translation so that our initial experience of these environmental issues is palatable enough that we decide to learn more. Or perhaps finding and perceiving the aesthetic in a bleak place or situation is a necessary practice which enables us to begin to understand the nuance and complexity of issues around land use.

10. Making Art as an Ethical Act

The act of making art may in itself be an ethical response to these issues—formalist art critic Clive Bell certainly believed so.[72] Nietzsche was skeptical of the capacity of politics to solve our most difficult problems, arguing that aesthetic experiences might be necessary to understand and engage with the world.[73] Theoretical physicist Richard Feynman said "what I cannot create, I cannot understand." Christopher Preston considers Feynman's idea in the context of the human penchant to fabricate and design,[74] and it is only one step further to apply it to a studio practice.

Mark Dion writes about the act of representation as "responsible,"[75] and it is particularly interesting to consider his word choice. Responsibility contains the idea of response. Those who respond are putting themselves in active dialogue with the systems in which they operate. Perhaps one of the most important arenas for artistic response is questioning our institutions of knowledge. As science becomes increasingly complex, abstract, and difficult to present to the public,[76] we need interpreters more than ever. But who interprets data and how do those interpretations move into the realm of generally accepted truth? Dion points to museums, national parks, zoos, and horticultural centers as places which generate and disseminate an "official story."[77]

We are caught in a difficult situation as consumers of that story, because we in many cases need the expertise of these institutions to make sense of new knowledge and situate it in context, but we likewise need to be aware of flaws in the structures of these institutions and gaps in their narratives. Dion notes that language, naming, and labelling all help us organize and categorize, but can also distance us from what we are trying to make sense of.[78] There are, however, limits on how

[72] Clive Bell, *Art*, (London: Chatto & Windus, 1921), 20.
[73] Barrett, *Why Is This Art?*, 162-3.
[74] Preston, *The Synthetic Age,* 53.
[75] Corrin, "Mark Dion's Project," 48.
[76] Heon, *Unnatural Science*, 11.
[77] Mark Dion, "A Little Bird Told Me," *Mark Dion,* (London: Phaidon, 1997), 128.
[78] Corrin, "Mark Dion's Project," 53.

knowledge can be transmitted verbally, and it may be one of the unique challenges of multimodal sensory work to penetrate this framework which is accepted and often taken for granted.

Art has long been tied to institutions of knowledge. John Latham, who founded the Artist Placement Group with his wife Barbara Steveni in the 1960s, worked in the Scottish Office at Edinburgh to study the extractive shale oil industry there.[79] Robert Rauschenberg collaborated with Billy Kluver of Bell Labs to found the E. A. T. collaboration between artists and engineers around the same time.[80] Institutions like the Rocky Mountain Biological Laboratory in Colorado and Cedar Point Biological Station in Nebraska allow artists to work alongside scientists for extended lengths of time. The SymbioticA program at the University of Western Australia houses researchers from both art and science backgrounds and provides a framework in which they can conduct art-science research while also engaging in critical conversation about their practices.

In each of these examples, artists are not simply observing or interpreting science, but actively engaging in and critiquing scientific systems and practices. Perhaps, as Dion said, "in the era of managing resources now recognized to be limited, knowledge itself may be the resource whose historical limits we most urgently need to understand."[81]

[79] Gisela Williams, "Are Artists the New Interpreters of Scientific Innovation?" *The New York Times Style Magazine,* published September 12, 2017, accessed October 3, 2018, https://www.nytimes.com/2017/09/12/t-magazine/art/artist-residency-science.html.
[80] Ibid.
[81] Bryson, "Mark Dion and the Birds of Antwerp," 97.

11. Reflections and Conclusions

There are several elements in this piece I would like to note as areas to address in future related work. First, the correlation of each panel and fan with a specific height on one tree was not clear enough. The task of evoking a change in y-axis as viewers move along an x-axis is one I hope to continue investigating, especially in my upcoming work at a former peat extraction site in Northern Ostrobothnia, Finland. I hope to experiment with breaking the uniformity of panels, and changing the installation scenario to add to a feeling of tension as viewers move through the space, which may be able to better communicate a vertical movement.

The vellum paper has an important aesthetic translucent quality. In the future I would like to experiment with surface materials which are linked more closely to content, or ideally sourced from the content, such as hand-made paper from plant material I source on site.

I also hope to further separate the digital functions from the audience interface with the piece. While the real-time data translation remains interesting to me, I also hope to explore potential for collecting smaller samples of data and looping them in a gallery space, so the show viewers see may be situated in a specific moment. This will also avoid some potential technical challenges.

I have found it rewarding to combine technological processes with the hand-made mark. This pairing of digital and analog can raise questions about subjectivity and objectivity. I have found few other contemporary artists working with data as medium or concept who also incorporate the hand-made mark, and anticipate this may be a fruitful area to explore.

In *Second Wind*, air movement is a means to look at one specific organism, one specific tree. I hope to continue looking at land use and perception at the ecosystem level via individual physiology at the microscopic scale, and hope this narrow focus will allow viewers to connect to the plants I research while also giving them space to consider how the patterns within those plants are not so dissimilar from the patterns within us as humans.

12. Appendix A: Input Code

Written in Python programming language by collaborator Brian Givens:

```
# Set to your Adafruit IO key.
# Remember, your key is a secret,
# so make sure not to publish it when you publish this code!
ADAFRUIT_IO_KEY = '[insert here]'

# Set to your Adafruit IO username.
# (go to https://accounts.adafruit.com to find your username)
ADAFRUIT_IO_USERNAME = '[insert here]'

# Import libraries needed
import time
import busio
import digitalio
import board
import adafruit_mcp3xxx.mcp3008 as MCP
from adafruit_mcp3xxx.analog_in import AnalogIn
from Adafruit_IO import Client, Feed, RequestError


# Create an instance of the REST client.
aio = Client(ADAFRUIT_IO_USERNAME, ADAFRUIT_IO_KEY)

try: # if we have a 'treeforce0' feed
    treeforce0 = aio.feeds('treeforce0')
except RequestError: # create a treeforce0 feed
    feed0 = Feed(name="treeforce0")
    treeforce0 = aio.create_feed(feed0)
try:
    treeforce1 = aio.feeds('treeforce1')
except RequestError:
    feed1 = Feed(name="treeforce1")
    treeforce1 = aio.create_feed(feed1)
try:
    treeforce2 = aio.feeds('treeforce2')
except RequestError:
    feed2 = Feed(name="treeforce2")
    treeforce2 = aio.create_feed(feed2)
try:
    treeforce3 = aio.feeds('treeforce3')
except RequestError:
    feed3 = Feed(name="treeforce3")
    treeforce3 = aio.create_feed(feed3)
try:
    treeforce4 = aio.feeds('treeforce4')
except RequestError:
    feed4 = Feed(name="treeforce4")
    treeforce4 = aio.create_feed(feed4)

# create the spi bus
spi = busio.SPI(clock=board.SCK, MISO=board.MISO, MOSI=board.MOSI)

# create the cs (chip select)
cs = digitalio.DigitalInOut(board.D5)

# create the mcp object
mcp = MCP.MCP3008(spi, cs)


while True: #main program loop

    #read each flex sensor
    forceRead0 = AnalogIn(mcp, MCP.P0)
    forceRead1 = AnalogIn(mcp, MCP.P1)
    forceRead2 = AnalogIn(mcp, MCP.P2)
    forceRead3 = AnalogIn(mcp, MCP.P3)
    forceRead4 = AnalogIn(mcp, MCP.P4)
    print('Treeforce0 ->', forceRead0.value) #debugging, comment out if not needed
    #send data to IO
    aio.send(treeforce0.key, forceRead0.value)
    aio.send(treeforce1.key, forceRead1.value)
    aio.send(treeforce2.key, forceRead2.value)
    aio.send(treeforce3.key, forceRead3.value)
    aio.send(treeforce4.key, forceRead4.value)

    time.sleep(10.1) #wait before sending agai
```

13. Appendix B: Output Code

Written in Python programming language by collaborator Brian Givens:

```
# Set to your Adafruit IO key.
# Remember, your key is a secret,
# so make sure not to publish it when you publish this code!
ADAFRUIT_IO_KEY = '[insert here]'

# Set to your Adafruit IO username.
# (go to https://accounts.adafruit.com to find your username)
ADAFRUIT_IO_USERNAME = '[insert here]'


# Import libraries needed
import time
import busio
import digitalio
import board
import adafruit_tlc59711
from Adafruit_IO import Client, Feed, RequestError
#connect to io
aio = Client(ADAFRUIT_IO_USERNAME, ADAFRUIT_IO_KEY)

try: # if we have a 'treeforce0' feed
    treeforce0 = aio.feeds('treeforce0')
except RequestError: # create a treeforce0 feed
    feed0 = Feed(name="treeforce0")
    treeforce0 = aio.create_feed(feed0)
try:
    treeforce1 = aio.feeds('treeforce1')
except RequestError:
    feed1 = Feed(name="treeforce1")
    treeforce1 = aio.create_feed(feed1)
try:
    treeforce2 = aio.feeds('treeforce2')
except RequestError:
    feed2 = Feed(name='treeforce2')
    treeforce2 = aio.create_feed(feed2)
try:
    treeforce3 = aio.feeds('treeforce3')
except RequestError:
    feed3 = Feed(name='treeforce3')
    treeforce3 = aio.create_feed(feed3)
try:
    treeforce4 = aio.feeds('treeforce4')
except RequestError:
    feed4 = Feed(name='treeforce4')
    treeforce4 = aio.create_feed(feed4)

#connect to PWM controller
spi = busio.SPI(clock=board.SCK, MOSI=board.MOSI)
tlc59711 = adafruit_tlc59711.TLC59711(spi)

#function to remap a value to a new range
def valmap(x, in_min, in_max, out_min, out_max):
    return int((x-in_min) * (out_max-out_min) / (in_max-in_min) + out_min)

#main loop
while True:
    treespeed0 = aio.receive(treeforce0.key)
    treespeed1 = aio.receive(treeforce1.key)
    treespeed2 = aio.receive(treeforce2.key)
    treespeed3 = aio.receive(treeforce3.key)
    treespeed4 = aio.receive(treeforce4.key)
    #send out received values. The way the circuit is wired, high numbers make the fans slow, so
    #we are inverting the numbers (0 becomes 65535, 65535 becomes 0, etc..)
    tlc59711.r0 = valmap(int(treespeed0.value), 0, 65535, 65535, 0)
    tlc59711.g0 = valmap(int(treespeed1.value), 0, 65535, 65535, 0)
    tlc59711.b0 = valmap(int(treespeed2.value), 0, 65535, 65535, 0)
    tlc59711.r1 = valmap(int(treespeed3.value), 0, 65535, 65535, 0)
    tlc59711.g1 = valmap(int(treespeed4.value), 0, 65535, 65535, 0)
    #for debugging, comment out if not needed
    print('Treespeed0 ->',treespeed0.value)
    #wait, so we don't overwhelm the server
    time.sleep(10.1)
```

14. Appendix C: Altered Iron Gall Ink Recipe

Based on recipes found at irongallink.org:

- Fill one quart-size jar with food-processed (for maximum surface area) dried pine needles. Then, pour in distilled water, filling remaining space in jar. Ferment for approx 2 weeks.
- Boil 20g additional dried pine needles + 100g distilled water, until remaining water content is approx 30g when strained.
- Combine 33g ferrous sulfate (iron salt) with 45g gum arabic in bowl
- Strain and add 30g tannic ferment liquid and 30g tannic boiled liquid
- Mix and store in airtight container. Ink darkens slowly as iron contents oxidize

15. Bibliography

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